



Experiences with biomass in Denmark

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Experiences with biomass in Denmark



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PREFACE

The Bioenergy Department in SENER have requested assistance with planning for the deployment of bioenergy (Biomass, biogas and waste incineration) in Mexico and information on Danish experiences with developing policy initiatives promoting bioenergy.

This introduction to the Danish experiences with biomass use is compiled as preparation for SENER's potential visit to Denmark in 2014.

This report was prepared 19 June, 2014 by DTU System Analysis to Danish Energy Agency (DEA) as part of a frame contract agreement.

1 Introduction

Biomass is an umbrella term for organic substances that are ultimately derived from photosynthesis. One of the primary motivations for increasing the share of biomass within the national energy profile is the potential reduction in greenhouse gases and the contribution that biomass can make toward a more sustainable energy system. Among the options for renewable energy, bioenergy has the advantage that it can be stored and used for regulating power from intermittent sources such as solar and wind. Biomass can also be converted to a fuel for use in transportation, aviation, and heavy machinery. On the other hand, biomass is not freely available, like wind or solar; it requires continuous input of fuel to produce, transport, and process. Furthermore, biomass as a resource is constrained by competing end uses (food, fiber, ecology, etc.) for the same factors of production: land, water, nutrients, and energy. Therefore, policies should be crafted as to ensure biomass is sourced in such a way that it is economically, environmentally, and socially sustainable.

1.1 Biomass in Denmark: Summary

Biomass for bioenergy has been a part of Denmark's energy profile since pre-industrial times. The oil shocks of the 1970s compelled Denmark to rethink its energy portfolio, which at that time was dominated by imported petroleum. Biomass was incentivized and promoted as a renewable energy source and an alternative to fossil fuels. Currently, Denmark is striving to create an energy system by 2050 that is free of fossil energy altogether, and bioenergy will likely play a key role.

The principle biomass resources utilized in Denmark (aside from waste) are wood pellets, wood chips, and wheat straw. Predominately, biomass is combusted for heat and power, and since 1993, Denmark has been increasing the deployment of large-scale combined heat and power plants (CHP) that combust biomass. Retrofitting older coal-fired plants to biomass is also part of Denmark's strategy to reduce emissions. Finally, Denmark is investing heavily into Research, Development and Demonstration (RD&D) for converting agricultural residues to second-generation (2G) bioethanol, which is then blended with gasoline for the transportation sector. There are also RD&D activities on biodiesel for shipping and road transport.

Denmark is heavily reliant on imports, particularly of wood pellets - importing over 90% of the annual demand. Wood chips are also imported, while straw is domestically produced. Because of Denmark's size with respect to a growing global market for woody biomass, Denmark is a "price taker." Historically, however, prices for biomass have been less volatile than those for fossil fuels. Prices are projected to continue to increase for this resource into the future.

As part of the European Union (EU), Denmark is under commitments from the Renewable Energy Directive, which sets targets for the amount of renewable energy within the national energy profiles of EU member states. Denmark also participates in the EU Emissions Trading System (ETS), the world's largest emissions trading scheme. Denmark

has been proactive and ambitious in establishing targets for renewable energy and greenhouse gas emissions reductions.

The challenges ahead for Denmark include uncertainty in future energy demand and securing a reliable supply of biomass that is sustainably produced.

2 Resources

Seventy percent of renewable energy in Denmark is in the form of biomass. This consists predominately of straw and wood, but also includes biodegradable waste and biogas. Because biogas and municipal waste are covered in separate reports, this report focuses on plant biomass (agricultural and forestry products). Bioenergy consumption in Denmark has nearly doubled in the last decade, increased by more than a factor of twelve between 1970 and present day (Figure 1). Over this period, biomass is predominantly in the form of waste, straw and wood (Figure 1).

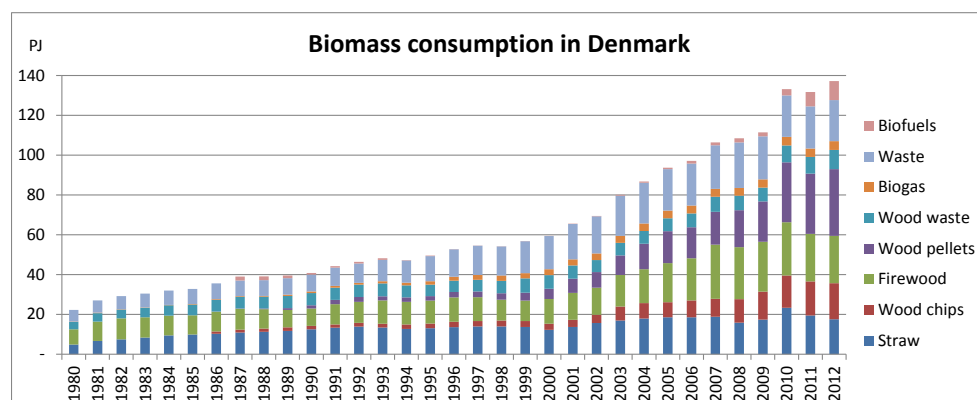


Figure 1. Historic consumption of biomass in Denmark (DEA, 2014a).

In 2012, Denmark produced 137 PJ of energy from biomass, comprising 18% of the 760 PJ in total energy demand (DEA, 2014a). By 2020, Denmark is expected to increase its share of renewable energy to 35%; likewise, the production of energy from biomass is expected to increase to 166 PJ (DEA, 2012a). In the long term, even a larger share of the Danish energy system is expected to be from renewable energy sources, and thus, depending on the scenario, consumption of bioenergy is expected to be between 200 and 700 PJ by midcentury (DEA, 2012a). It is estimated the midcentury potential for biomass production in Denmark is between 200-245 PJ (excluding organic waste), so trade in biomass will be a large component of Denmark's future energy landscape (DEA, 2012a).

2.1 Domestic



Table 1 shows the different types of biomass consumed for energy purposes in Denmark. The domestic resources are dominated by straw, firewood and biodegradable waste. Straw is a residue from the agricultural production of grain, much of which is used for combustion in CHP plants. The total resource of straw available for energy

production (straw needed for bedding and feed is subtracted) is about 2.7 million tonnes, of which about half is used. At the moment, it is not economical to use a larger proportion of the resource, but minor technological adjustments could expand access to the resource (Jørgensen et al. 2013). The majority of the biodegradable waste used for energy production stems from private households. This resource is fully used (i.e. incinerated or used for biogas) and has been declining during the past years. This decline is expected to continue due to policy measures to reduce the generation of waste in society in general, thus a greater supply of other biomass sources may be necessary to compensate. The forestry industry is the largest contributor of biomass to the energy system today with a total of 44 PJ, which represents nearly half of the domestic biomass consumption in Denmark.

Biomass	Domestic production	Imports	Total
Straw	17.5	0	17.5
Wood chips	12	6.2	18.2
Firewood	20.5	3.3	23.8
Wood pellets	1.7	31.8	33.5
Wood waste	9.7	0	9.7
Waste, biodegradable	20.6	0	20.6
Biofuels	2.5	7	9.5
Biogas	4.4	0	4.4
Total	88.9	48.3	137.2

Table 1. Biomass consumption (PJ) in 2012 (DEA; 2014a)

Only a small amount of agricultural land is used for dedicated energy production. There is a total area of about 8,500 ha of willow and poplar, which is used to produce wood chips. Currently, large-scale production of dedicated energy crops in Denmark is not possible without reducing the production of food and feed. Because of the potential competition for land between energy crops and crops for food and feed, the current focus in Denmark is on the use of agricultural and forestry residues as well as organic waste for energy. However, dedicated energy crops may have a future potential for several reasons. First, it is expected that improvements in technology and cultivation techniques will increase

future crop yields. If food and feed production is held constant, the increased yields could open up land for energy production. Second, the further development of bio-refineries to produce a wider range of valuable co-products, such as extracting proteins from biomass to use for animal feed as part of a bioethanol production, this could also incentivize growing biomass for energy purposes (Jørgensen et al. 2013).

2.2 Imports

Aside the domestic sources of biomass, almost three million tons of woody biomass and 5.5 PJ of liquid biofuels was imported to Denmark in 2011. Currently, Denmark imports about 35% of the biomass consumed. Two thirds of the imported biomass is in



the form of wood pellets. Importation of biomass for energy use on a larger scale began in the mid-1990s (Figure 2). The vast majority of these imports have been wood pellets and wood chips for use in combined heat and power (CHP) plants, district heating plants, and private domestic burners (DEA, 2013). It is likely there will be an increase in the importation of wood pellets (for combustion in CHP plants) and of maize and sugar cane (for the production of liquid fuels for the transportation sector). The woody biomass is used for firing in heat and power plants, and for heat production in private households. Recently, furnaces fired with wood pellets have become popular in Denmark due to the increasing price of oil (DEA; 2012a). This has resulted in a dramatic increase in imports of woody biomass within the last few years and this tendency is expected to continue.

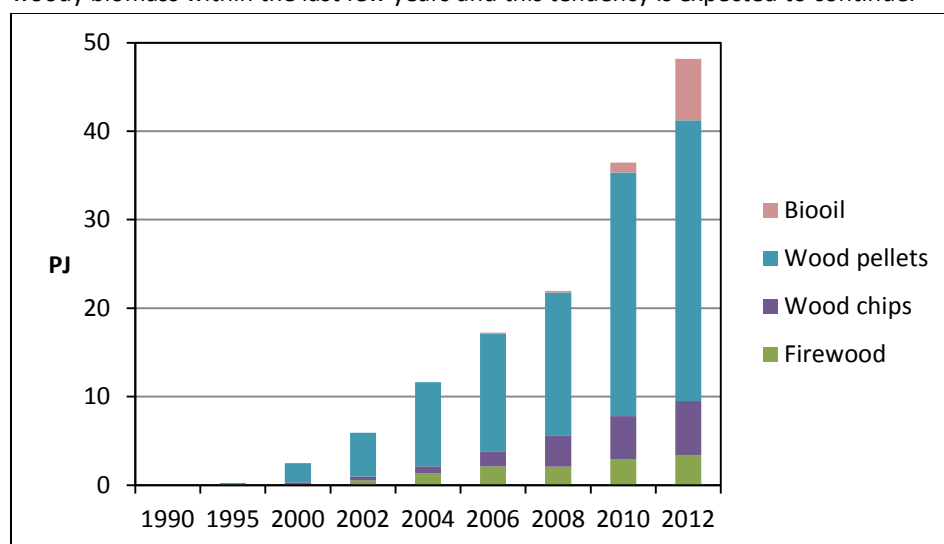


Figure 2. Imported Biomass for Bioenergy in Denmark

3 Technology

3.1 Biomass consumption technologies

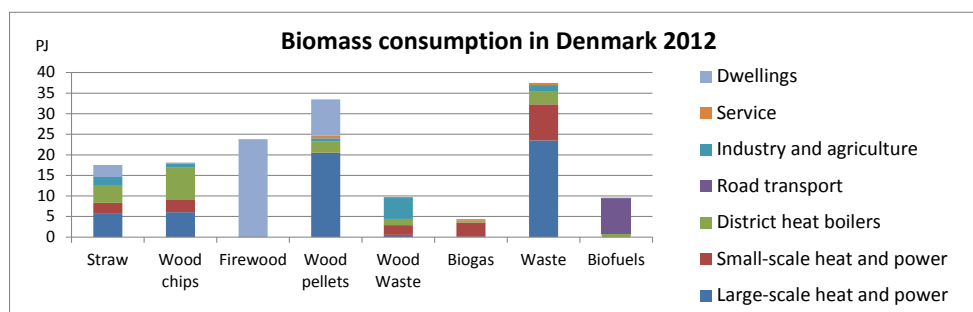


Figure 3 Biomass Consumption in Denmark 2012 (DEA 2014a)

The technologies used for the various types of biomass are illustrated in Figure 3 for the year 2012. Firewood is used in stoves in single-family dwelling, often as a supplement to the central heating system, while wood pellets and waste are mainly used in large power plants. In addition to the biodegradable waste, which is counted as renewable, nearly the same amount is incinerated, but counted as non-renewable waste in Danish and international statistics. A broader range of technologies are used for combustion of straw, wood chips and wood waste, and biofuels are converted to liquid fuels to be used for road transport.

3.2 Biomass combustion in large-scale power plants

The Avedøre 2 power plant, a CHP plant owned by DONG Energy, can use several types of fuel: natural gas, oil, wood pellets and straw. When commissioned in 2001, it was the world's most efficient CHP plant. As a result of cogeneration of heat and power, up to 94% of the fuel energy is utilized at maximum district heating production. The unit consists of three modules: a steam turbine plant with supercritical pressure, a gas turbine plant, and a biomass plant. The total capacity is 495 MWe and 575 MJ/s heat. The efficiency is 49% in condensation operation (electricity only) and 93% in CHP operation. Natural gas and oil are co-fired with wood pellets in the 70-meter high steam boiler at a temperature of 1,500 °C. Prior to combustion, the wood pellets are pulverized in large mills. This is similar to conventional pulverized coal technology, for which the boiler was originally designed.

The straw-fired biomass plant consists of a straw storage, one boiler, an ash separator and a plant for processing of bottom ash and fly ash. The plant is the largest in the world of its kind. The biomass boiler supplies steam to the unit's main turbine. The capacity is 45 MWe and 50 MJ/s heat. At maximum production, 25 tonnes of straw are fired per hour, corresponding to 50 straw bales of 500 kg each. The straw is supplied by contracting farmers within a 100-km radius of the plant. From the plant's straw storage room, the straw is transported to the boiler on four conveyor belts. A straw shredder placed at



the inlet to the boiler loosens the straw before it is fed into the boiler by feed screws. The steam is led from the biomass boiler to the main turbine, which allows a flexible use of boilers and fuels.

3.3 Refurbishment of fossil fuel-fired power units to biomass use

Part of Denmark's strategy in reducing fossil fuel use is to convert existing coal power plants into biomass use. In the City of Aarhus, for example, the Studstrup CHP plant built in the mid-1980s will be refurbished for wood pellets as part of its ongoing renovation. Additionally, the refurbishment of existing coal and oil-fired power plants in Copenhagen, the Amager 1-3 units, has enabled the use of biomass for CHP. Between the years 2005-2010, the Swedish energy company Vattenfall completely rebuilt these coal-fired units, which date from the early 1970s, to combust straw and wood pellets. Until 2013, straw was converted to straw pellets some 40 km from the power plant, with barge transport to the plant. In 2013, the Amager 1-3 units were acquired by the company HOFOR, owned by the municipalities in the Copenhagen metropolitan area. In the coming years, the newest Amager unit (from 1989) will be converted to wood chips. The conversion to woodchips is more expensive than to wood pellets, but has the advantage that woodchips are cheaper than wood pellets and that the conversion loss in the creation of pellets is avoided. In addition, wood chips may be supplied from Europe, where the management of forests is generally more sustainable than in many other regions.

3.4 Small-scale biomass combustion

Before 2000 biomass was combusted mainly in smaller units, either for individual heating or – from the 1990s onwards – also for supply of local district heating grid, The technologies for individual boilers are wood stoves for direct room heating or boilers for central heating of small and large buildings. Various types of firewood are used for wood stoves, while wood chips or wood pellets are used for biomass boilers with manual or automatic stoking. In particular wood pellet boilers with automatic stoking have become an alternative to oil boilers in houses with no access to district heating or natural gas grid. Particle emission has become a major environmental problem from wood stoves, 50 g/GJ fuel, compared to 15 g/GJ fuel for biomass boilers with manual stoking, and 10 g/GJ fuel for automatic stoking.

Decentralized combined heat and power (CHP) became important in the 1990s; the preferred fuel in most of the country was natural gas for combined cycle gas turbines. In the few regions without natural gas, biomass was used either for biogas or combustion of solid biomass. However in these regions waste incineration is used for the largest units. The best example of use of solid biomass for CHP is the Maribo-Sakskøbing CHP unit. It started in 1999 with the capacity 9 MW electricity and 20 MJ/s heat. It burns 50,000 tons of straw from farmers within a 20-30 km radius. and supplies two small towns with district heating. The electricity is fed into the national grid. Until recently the plant was owned by DONG Energy. It is now owned and operated by the same company that runs the regional waste incineration plant.

3.5 Biomass conversion to liquid biofuels for transport

There are a number of possible routes through which biomass can be converted to biofuels. Conventional or first-generation (1G) technologies include well-established processes that are already producing biofuels at a commercial scale, including sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion (Figure 4).

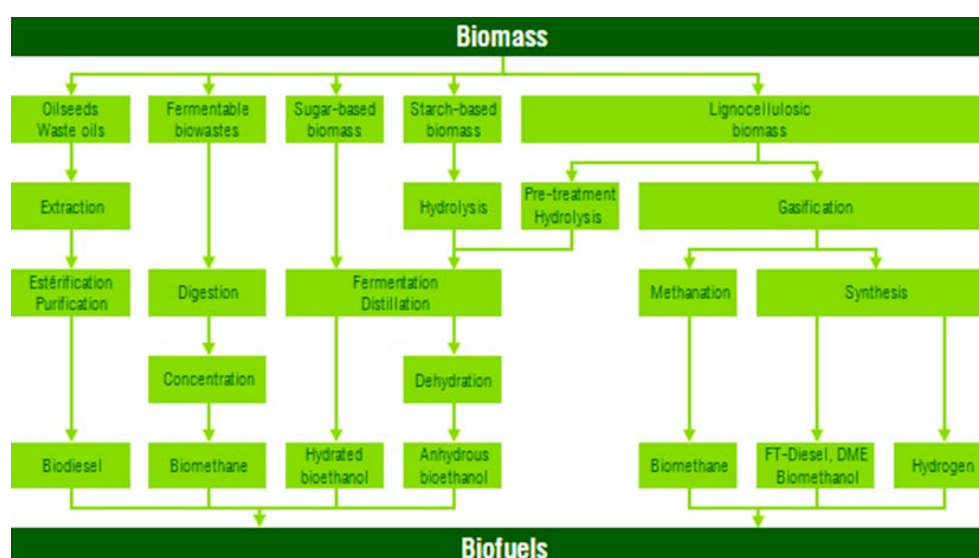


Figure 4. Biomass to Biofuel technology pathways (OECD/EA 2011).

There is some production of 1G biodiesel in Denmark, by Emmelev (www.emmelev.dk) based on rape seed, and by Daka ecoMotion (www.dajaeconomotion.dk) based on animal fat and other residual products not suitable for use in feed production. Several research, development and demonstration (RD&D) projects on the production and use of biodiesel – both 1G and 2G – in road transport as well as in shipping have been undertaken. These activities are often carried out in partnerships between research organizations (e.g., Danish Technological Institute, Technical University of Denmark, University of Copenhagen, and University of Aarhus) and companies (e.g., Novozymes, Haldor Topsoe, Emmelev, A.P. Moller Maersk, DONG Energy, and MAN Diesel & Turbo). Examples are the use of enzymes in biodiesel production, and the development of integrated bio-refining technologies for shipping fuels and bio-based chemicals. Danish companies develop and produce enzymes and other technologies for 1G ethanol production in other countries, e.g. the US and Brazil, but there is no large-scale production of 1G bioethanol in Denmark.

Advanced biofuel technologies are conversion technologies which are still in the research and develop, pilot or demonstration phase, commonly referred to as 2G or 3G (OECD/IEA, 2011). This category includes hydrotreated vegetable oil (HVO), which is based on animal fat and plant oil, as well as biofuels based on lignocellulosic biomass, such as cellulosic-ethanol, biomass-to-liquids (BtL)-diesel and bio-synthetic gas (bio-SG). The category also includes novel technologies mainly in the R&D and pilot stage, such as algae-based biofuels (OECD/IEA, 2011).

It is anticipated that developing technology to produce fuels from a variety of lignocellulosic biomass sources (e.g. agricultural and forestry residues and lignocellulosic energy crops) and a portfolio of conversion routes for power, heat and gaseous and liquid fuels will allow the production of large amounts of biofuels and will, at the same time, minimize environmental and social impacts (IPCC, 2011, p. 219). Compared to those based on starch or sugar, biofuels based on lignocellulosic materials can potentially replace large amounts of fossil transport fuels. This is due to high feedstock yield per area unit, low feedstock costs, the possibility of producing feedstock on land unsuitable for food production, and the relatively large GHG emissions reductions.

Cellulosic ethanol (CE) is to date the most advanced type among the advanced biofuels in terms of the scale of production. While CE for non-fuel uses has been produced for decades in smaller quantities, CE production for transport fuels at a commercial scale has been limited by inefficient process technology and difficulties in sourcing and transporting feedstock in sufficient amounts. Several commercial-scale CE facilities are nevertheless now being deployed in Europe and the US. In Denmark, one commercial scale facility is planned, the Maabjerg Energy Concept, and there are two CE demonstration plants in operation: the Inbicon bioethanol plant in Kalundborg owned by DONG Energy (Larsen et al., 2008, Bolwig and Amer, 2013, see Section 8) and the BornBioFuel2 plant on Bornholm built by Biogasol Aps (Langvad et al., 2010).

3.6 Danish-funded RD&D programs relating to biofuels

In general, public research funding has stimulated research on bioenergy in Denmark, including on liquid biofuels (Olsen, Klitkou and Eerola, 2013). From 2008 to 2011, the Danish government provided over € 450 million on energy RD&D, of which 25% went into bioenergy and waste (DEA, 2012b). In 2009, € 15 million or 14% of the total energy RD&D

budget went into liquid biofuels; most of these funds have been spent on demonstration projects (OECD/IEA).

Several public funding programs in Denmark have supported biofuel development, including support to demonstration plants and the testing of improved production processes in these plants or in the lab. The DEA is responsible for several programs, such as the Energy Research Programme (1976–2008), the Energy Technology Development and Demonstration Programme (EDDP, from 2007) and Green Labs DK (from 2010).

The EDDP provides important guidelines for the direction of future developments in energy technologies, and advanced transport biofuels and the integration of energy technologies are among the prioritized areas. EDDP has funded many biofuels demonstration projects; recent ones include: industrial scale straw-to-bio-methane conversion (C. F. Nielsen A/S, 2012–15); high yield fermentation process for 2G bioethanol production (Terranol A/S, 2012–15); bio-oil from biomass and waste (Organic Fuel Technology A/S, 2012–14); advanced methanol synthesis technology (Haldor Topsøe A/S, 2012); REnescience waste refinery (DONG Energy A/S, 2010–12); BornBioFuel2: A fully integrated 2G bioethanol demonstration plant on Bornholm based on the Maxifuel concept (Biogasol Aps, 2009–12); and the construction of a demonstration plant for 2G bioethanol production at Kalundborg (Inbicon A/S, 2008–10) where new bioethanol technology has been tested and prepared for commercial-scale deployment.

Green Labs DK supports the Green Gas Test Centre (2011 –) hosted by Danish Gas Technology Center (DGC). The work involves biogas upgrading, metering, gas quality requirements and control, testing of appliances on biogas and other gases, standardization and environmental and health issues. In a wider sense, DGC works on how to combine natural gas and renewables allowing for a gradual transition to a greener energy system alongside the maturing of RE-technologies.

The Danish Council for Strategic Research, under the Ministry of Higher Education and Science, has also funded many projects relating to biofuels, including, recently:

- 2014-18: H2CAP–Hydrogen assisted catalytic biomass pyrolysis for green fuels; NomiGas– Novel microbiological platform for optimization of biogas production;
- 2013-17: BioChain–Optimization of value chains for biogas production in Denmark; SYMBIO–Integration of biomass and wind power for biogas enhancement and upgrading via hydrogen assisted anaerobic digestion; ASHBACK–Ash from biofuel in energy plants back to the forest and field and the eco-toxicological consequences;
- 2012-16: BIORESOURCE–Increasing the biomass resource, its quality and sustainability; RESAB–Rational engineering of cellulases for improved saccharification of biomass; SET4Future–Sustainable Enzyme Technologies for Future Bioenergy; MycoFuelChem– Consolidated bio-processing of biomasses into advanced fuels and high value compounds in fungal cell factories; MacroAlgaeBiorefinery–Sustainable production of 3G bioenergy carriers and high value aquatic fish feed from macroalgae;

Danish companies and research institutions also participate in a range of Nordic and EU biofuel projects. For example, the bioethanol process technology used by Inbicon A/S was developed partly through large projects funded under the EU FP5 during 2002–06 and the EU FP7 during 2009-13. Another example is the participation of the Danish Technological Institute in the project *Biowaste and Algae Knowledge for the Production of*

2nd Generation Biofuel (2010-14) funded under the EU FP7. Participation in such international research projects is a key factor for Danish companies' efforts to develop and commercialize biofuel technologies.

3.7 Industrial symbiosis in energy production

Under the heading of “industrial symbiosis” the exchange of flows of waste materials or energy between independent industries have emerged at multiple locations, generally leading to savings of energy and sometimes also materials and resources thus increasing eco-efficiency (Chertow 2007). The Maabjerg Energy Concept (MEC) in western Denmark represents such a case. The MEC project merges several energy supply objectives in a holistic system concept, where the synergy between the individual solutions is used optimally and with great effectiveness, through the utilization and alignment of energy streams between the individual plants. Based on local biomass and waste resources, MEC will produce heat and electricity, biogas and bioethanol, and use the remaining nutrients as fertilizer (Figure 5).

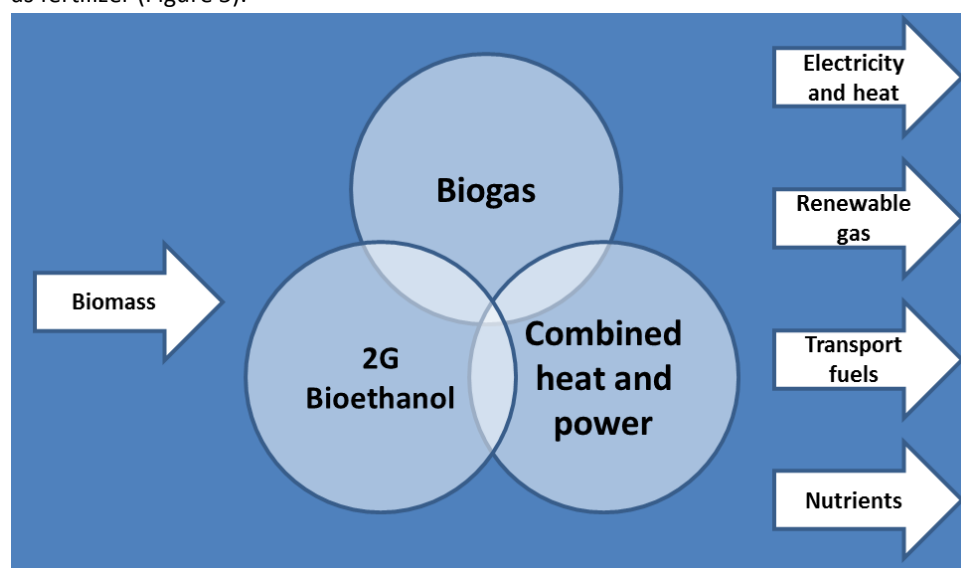


Figure 5. The Maabjerg Concept: industrial symbiosis based on biomass.

The combined system is dimensioned so that the local heating market can take the whole heating load from the plant, without energy being lost to additional cooling. The district heating system acts as a cooling medium for the steam required to produce ethanol. The extent of bioethanol production and the amount of raw materials needed is therefore based on the district heating system's base load. The residue from the bioethanol production, which consists of fiber and molasses, is used for energy production. The fiber is used to produce steam (and electricity) in the cogeneration plant, and the molasses is used in the biogas plant to produce biogas. Since it is necessary to use local household waste, this is processed using *REnescience* technology. This technology uses enzyme treatment to split the waste into a bio-liquid, used to produce biogas, and a solid part, which, after recycling, is used to produce heat and electricity. The technology makes it possible for the solid waste to be stored and used outside of the low load season. Biogas that cannot be used in the process or locally is upgraded to natural gas quality; part of this upgrade is done using hydrogen produced from wind power. The upgrade biogas is distributed in the natural gas network, and acts as a balancing storage capacity for the

electricity produced by wind turbines. The CO₂ produced by the processes in the plants is converted to pure methane.

The project's liquid fraction is used as fertilizer in agriculture. In the same way, the plant that harnesses the energy in the fiber from the biogas plant and the lignin from the ethanol production is designed so that the nutrients in the fiber and lignin are collected and exploited. In particular, using the phosphorus is essential, since this component has a large and global significance.

The MEC facility will be suited to receive farm manure (pig, cattle and mink), energy crops (e.g. potato pulp), crop residues (straw), biological waste (e.g. whey from a dairy plant), sludge from the local sewage treatment plant, and household waste (municipal solid waste). Currently, manure is sourced from farmers within a 20 km radius of the plant and transported with special slurry trucks. The farmers can collect the digestate fiber at the plant and use it as fertilizer. Straw to be used in bioethanol production will be sourced from farmers in a radius of about 100 km from the plant.

Today MEC produces biogas and combined heat and power while the establishment of the bioethanol plant awaits a more favorable policy environment at EU level (i.e., a mandatory 2G biofuel blending target). The ethanol production will be based on the Inbicon technology discussed earlier. Today, the biogas produced at Maabjerg BioEnergy provides heating for more than 5,000 households and power for more than 14,000 households. When fully developed, the MEC plant will consume 300,000 tons of straw, 800,000 tons of other biomass, and 100,000 tons of waste, sourced from its hinterlands. It will then produce 80 million liters of bioethanol, 50 million cubic meters biogas, and power and district heating for 25,000 households.

4 Economics

Biomass is an internationally traded resource, and thus an economic assessment of biomass in Denmark must also consider the price signals from the larger international biomass market. Global demand for biomass for bioenergy is also expected to increase, so the DEA is expecting moderate increases in biomass prices through 2050, noting that it is highly dependent on future scenarios for land use, diet and climate policy (Bang et al., 2013).

Currently, global consumption of biomass for energy is approximately 53,000 PJ/year, representing approximately 12% of total global primary energy consumption. Biomass is the largest source of renewable energy globally, contributing approximately 80% of the global supply of renewable energy. By way of comparison, this is five times the current amount of energy that wind power currently generates globally.

To meet the growing demand for biomass in Denmark, imports of woody biomass are making up an increasing proportion of the biomass supply. The long term challenge beyond 2020 is ensuring that the domestic and imported biomass is sustainably produced. A further challenge is the effects of an increase in biomass demand on indirect land use change that may negatively impact food prices, GHG emissions, biodiversity, and livelihoods. For instance, if the world adopts ambitious GHG emissions reduction and renewable energy targets, such as Denmark has, it could dramatically increase global

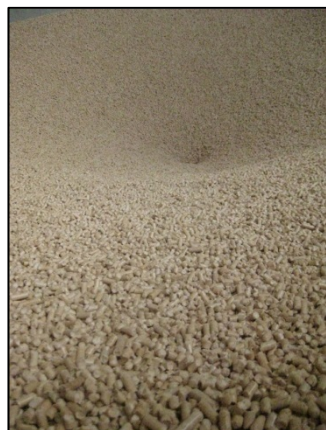
demand for biomass. This could lead to a situation where the technology that consumes biomass becomes locked-in through infrastructure investment, but the amount of sustainable biomass available globally becomes constrained.

Moreover, if demand for sustainable biomass increases too far beyond Denmark's ability to supply it, Denmark could become vulnerable to price volatility in this energy feedstock. In relation to this, Bang, et al. (2013) argue that as global bioenergy demand increases, global trade in biomass will correspondingly intensify, translating to more liquidity in the market, and more price competition. Because of its small energy demand compared to the global scale, Denmark is assumed to be a "price-taker" in the global biomass market (Ibid). Moreover, improved access to global markets will cause prices on local biomass (e.g., straw from Danish fields) to approach the global CIF (Cost, Insurance and Freight) prices (ibid).

Because of the rapid increase in the demand for solid biomass in the Nordic, Baltic, and other European countries, any increase in biomass production in this region is expected to be used to meet the growing domestic energy demand and so will not enter global trade streams. Nordic countries such as Sweden and Finland have vast forest resources, yet because of their remoteness and the slow growth rate of the trees, increases in supply from these countries is expected to be limited (Bang, et al. 2013). Russia also has substantial forest resources, but trends here are difficult to forecast. Western Africa is also a potential source of biomass imports to Europe, but political instability and difficulties in implementing sustainability criteria are important risk factors. The US and Brazil arguably have the greatest potential to supply Europe with sustainable biomass (Bang, et al. 2013). Solid biomass types (wood pellets, wood chips, and straw) have the greatest technical economy of scale, and are increasingly used in cogeneration power plants rather than simply for district heating production.. However, one of the potential challenges up to 2020 that Denmark faces is the loss in tax revenue from the energy system form incorporating more, efficient large-scale CHP biomass power plants, and with the corresponding phase-out of small scale CHP plants.

4.1 Wood Pellets

Wood pellets continue to command a much higher price than coal, and therefore depend on government support to reach market penetration (Roh, et al. 2013). Policies such as the EU Renewable Energy Directive have led to an increase in wood pellet trade, which



increased from 45 to 57 PJ between 2010 and 2011 at the global level (Ibid). Wood pellet production is dominated by North America and the EU (Figure 6). International trade centers on the EU (Figure 7) which is the major global consumer of wood pellets and includes four of the top five countries in terms of consumption: Sweden, Denmark, The Netherlands, and Italy (Figure 6). It is noticeable that this group includes countries with small populations, including Denmark. The majority of imported wood pellets into the EU originate in Canada and the US (Figure 7). The global trade in wood pellets is expected to increase in volume and number of countries involved as a result of

the rising demand for biomass for energy.

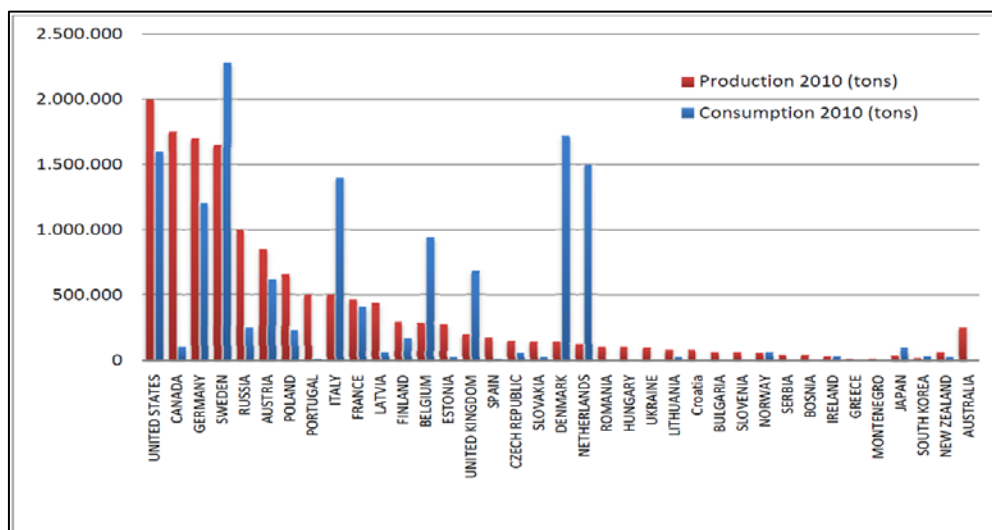


Figure 6. National levels of wood pellet production and consumption for the year 2010, taken from Bang, et al., (2013) and based on Cocchi, et al. (2011).

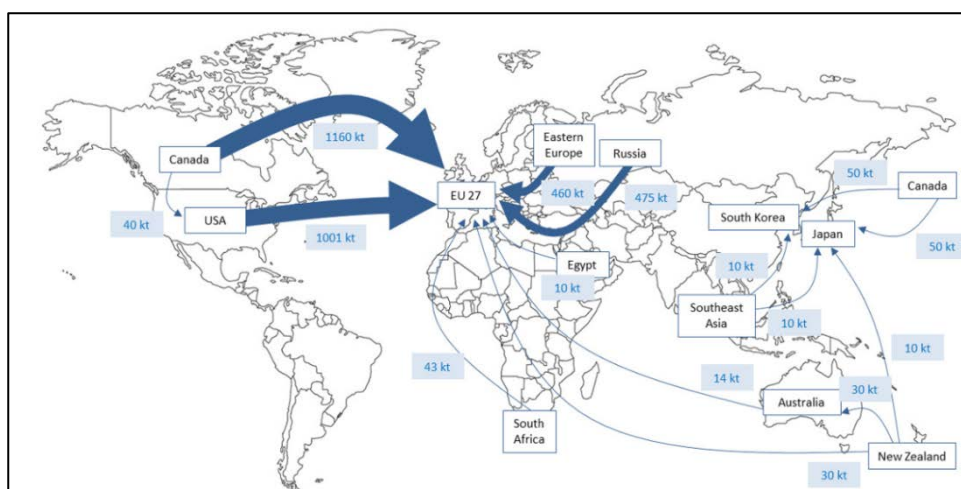


Figure 7. Global trade in wood pellets in 2011 in kilotonnes. Source: Goh, et al. (2013).

In Denmark, the consumption of wood pellets far exceeds domestic production so that nearly 95% of the wood pellets consumed are imported, mainly from the Baltic region, Sweden, and Germany (Evald, 2013). Liberia, Portugal and Russia also export considerable amounts of woody biomass to Denmark (Jørgensen et al. 2013) as well as North America.

4.2 Wood Chips



International trade in wood chips within the pulp and paper industry is not new, but trade in wood chips for energy purposes is a more recent occurrence; today an estimated 10% of global trade in wood chips is for energy purposes (Bang, et al., 2013). The world leaders in wood chip

production in 2009 were Canada, Australia, Sweden, Russia, China and Finland. As the pulp and paper industry moves from northern countries to southern countries, it is expected that wood chip sources will also move south, to include countries in South America and Southeast Asia (Lamers, et al. 2012). In Europe, major wood chips producers are the Baltic countries, Finland, Russia, and countries on the Balkan. The latter region exports mainly to Italy and its neighbors, while exports from the former three regions are destined for Denmark, Sweden and Germany.

4.3 Straw and Other Agricultural Residues



With the exception of palm kernel shells, agricultural residues are not traded in any significant amount on the global market. This is due to their low energy density and low cost competitiveness compared to woody biomass. They thus remain primarily a local and national

resource. In Denmark, wheat straw is dominant agricultural residue.

In Denmark, Dong Energy and Vattenfall purchase approximately 950,000 tonnes of straw per year, making them the largest consumers of straw for energy purposes. Transportation costs for straw are high compared to wood on an energy basis, and procurement contracts are typically made for growers within a 75 km distance (Bold, 2009; Holst 2010). Growers submit bids on the amount of straw that they can deliver to specific plants at a given price.

The following factors would stimulate international trade in agricultural residues: a substantial increase in biomass demand (e.g., due to increased efficiency of 2G bioethanol production); constraints on woody biomass supplies (e.g. as a result of implementation of tight sustainability standards), and an increased price on carbon in major markets.

4.4 Prices

The total price for delivered woody biomass includes the cost of the resource itself, inland transport to the site of processing, processing, and sea transport (Bang et al., 2013). The processing of wood pellets is more expensive than for wood chips, but lowers the cost of sea transport (Table 2).

Price Components	Wood Pellets		Wood Chips	
	USD/GJ	%	USD/GJ	%
Base Price	4.22	37%	4.22	51%
Inland Transport	1.63	14%	1.63	20%
Processing	4.35	39%	1.09	13%
Sea Transport	1.09	10%	1.36	16%
Total	11.29	100%	8.30	100%

Table 2. Price components for woody biomass. Data converted from Bang et al., 2013.

In contrast to the international market for fossil fuels, where spot-market prices exist, biomass for bioenergy is traded primarily through bilateral contracts and price agreements are made within each contract. By conducting a sample of these prices, an average commodity price can be calculated for the different sources of biomass over time (Figure 8).

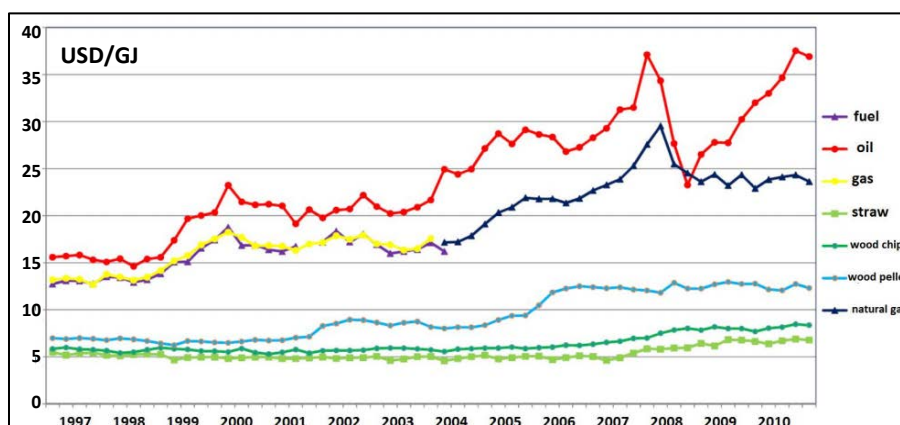


Figure 8. Weighted plant-gate historic prices (converted to USD/GJ) for fuels used in heating, excluding the Value Added Tax, but including energy and CO₂ for fossil fuels. Up until 2014, biomass is exempt from energy and CO₂ taxes. Data from the Danish District Heating Association, (2011).

Prices are highly influenced by political decisions such as taxes, subsidies, and national targets for renewable energy and CO₂ emissions reductions. Price volatility for biomass is much less than for fossil-based heating fuels (Figure 8). Prices are forecasted to continue to rise in the future due to a projected increase global demand (Figure 9). Future price trends depend on future trends in climate policy, agricultural productivity and diets (animal product demand, in particular) (Bang et al., 2013).

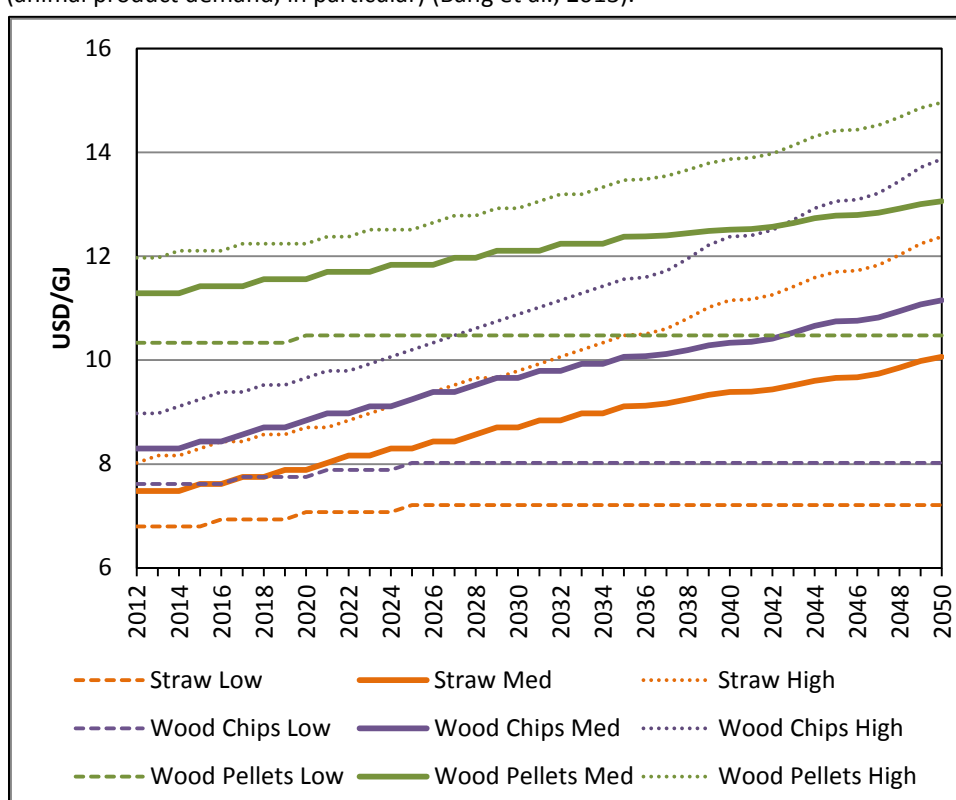


Figure 9. Future price projections for biomass for bioenergy. Three price scenarios are given for each resource, with different assumptions about future climate polices, agricultural productivity, and global diet. Data converted from Bang et al. (2013).

5 Policy and Regulation

5.1 Historical Perspective

Historically, biomass was dominant as fuel for room heating and land transport (horse fodder), while small-scale wind and hydropower was important in agriculture and for early industry. In the 19th and 20th century fossil fuels became dominant. By the early 1970s, Denmark was highly dependent on oil, leading to concerns about the security of supply. At the time of the 1973 oil crisis, over 90% of Denmark's energy came from oil, the majority of which was imported. Denmark was highly impacted, and instituted carless Sundays and other energy saving measures. The Danish energy plans from 1976 and 1981 aimed to reduce the oil dependency and secure energy supplies.

The use of biomass in the Danish energy system has grown continuously over the last 40 years (Figure 1). This development can be traced back to several energy policy agreements in Denmark (DEA, n.d.). "Energy plan 81" focused on energy savings and infrastructure for district heating and natural gas with newly discovered resources in the North Sea. Also a broad range of renewable technologies were considered, mainly for energy research focusing on small-scale technologies including biomass. Waste incineration and combined heat and power were important to expand district heating systems. The most important change in the shorter term was a shift from oil to coal. Nuclear power as an alternative to coal gave rise to fierce controversy, and was finally excluded by the parliament in 1985 due to strong public opposition (DEA, 1985).

The first combined heat and power (CHP) plants fired with wood chips were built in the 1980s. Support for the use of straw and wood chips together with leveraged fees on fossil fuels started to make biomass competitive (Serup et al., 1999). An energy policy agreement in 1986 specified the construction of decentralized CHP plants with 450 MW electric power, whereof 100 MW from biomass. A support scheme for biomass use in CHP plants was introduced as a part of Denmark's third energy plan, Energy 2000 from 1990 (Jørgensen & Andersen, 2012). The justifications behind the use of biomass were carbon neutrality, energy security, creation of Danish jobs, and utilization of waste products (Serup et al., 1999).

A binding target for the reduction of CO₂ emissions up to 2005 led to a political agreement on biomass in 1993 (DEA, 1993). This plan sparked the development further, focusing on co-firing of biomass with coal in larger power plants and a gradual shift to biomass power plants when technological challenges were overcome. The agreement in 1993 specified that centralized power plants should use 19.5 PJ/year of biomass by 2000 with certain shares from wood chips and straw. Amendments to the agreement were made in 1997 so that the different sources of biomass could be adjusted according to annual variations, with the purpose to achieve better market conditions (DEA, 1997). The fourth energy plan, Energy 21, released in 1996 specified that the total use of biomass should increase from 61 PJ to 85 PJ by 2005 and to 145 PJ by 2030 (Serup et al., 1999). This target was met already in 2012 (Figure 1).

The technology for use of biomass in large power plants has been improved during the last 20 years, and this development is expected to continue. The Danish energy industry, with a history in research, development and construction of power plants, boilers, and district heating grids, were believed to benefit from a focus on biomass for energy. The export potential for the technology is mentioned in several official documents (DEA, 1995; Danish Ministry of Environment and Energy, 1996).

5.2 Legislation

Denmark has played a major role in two EU climate policy areas: in EU's GHG reduction objectives and in relation to the discussion of the third phase of the EU Emissions Trading System (EU ETS). Danish climate regulation is framed in the context of EU climate policy, but is often more ambitious, for example in relation to GHG emissions reduction objectives in sectors such as agriculture, transport, heating of buildings, and waste.

Energy security plays a major role in Danish climate and energy policy. An important motivation behind the goal of being independent of fossil fuels in 2050 is to enhance energy security in the context of an increasing global demand for energy and the depletion of fossil fuel resources. This is reflected in an energy security fee, which includes all heating that comes from coal, oil, gas, and biomass. The fee for biomass is much lower than for fossil fuel

5.2.1 Climate Agreement

The Climate Agreement from 2012 defines the response to climate change in Denmark. The agreement will increase the production of sustainable energy from wind turbines, biogas and biomass, and increase energy efficiency, among other goals.

The Danish Government has set climate targets aiming to reduce overall national GHG emissions by 40% by 2020 relative to 1990 levels (DEA, 2011):

- All sectors, including those not currently covered by the EU ETS, should contribute with concrete and verifiable reductions by 2020 and beyond.
- The long-term target is for Denmark to contribute to the EU's objective of reducing GHG emissions by 80-95% by 2050 relative to 1990 levels, as part of a concerted global effort.
- Within the EU, Denmark has committed to reducing non-ETS emissions in the period 2013-2020 rising to 20% reduction in 2020 compared to 2005.
- All of Denmark's energy supply should come from renewable energy sources by 2050.
- Towards this goal, heating oil and coal will be phased-out by 2030, the electricity and heat supply must be covered 100% by renewable energy in 2035, and all energy for transportation must be renewable in 2050.

5.2.2 Biomass

Biomass consumption in Denmark is expected to keep increasing, stimulated first by the Biomass Agreement from 1993. A large majority of the Danish parliament supported a measure that requires 1.4 million tonnes of straw and woody biomass to be used annually in CHP power plants, equivalent to 20 PJ/year. The biomass agreement from 1993 has led to the use of biomass in several large-scale power plants and many smaller plants. This is consistent with the Danish tradition for flexibility in fuel use and operation in the Danish power industry.

A policy from 2008 aimed to optimize overall energy efficiency. It also aimed to promote sustainable energy in accordance with climate, environmental and socio-economic concerns, and to reduce fossil fuel dependence. Biomass is one of the sustainable energy sources identified in this law, along with wind power, hydropower, solar power, biogas, tidal energy, and geothermal. The policy specifically demanded an increase in the use of straw and woodchips for co-firing in large power plants, as opposed to biomass used for heat production. The new target was set to 700,000 tonnes of biomass per year by 2011. Denmark has various support schemes for biomass production, which of course affects some bioenergy value chains. Planting perennial energy crops such as willow and poplar has been supported by the Ministry of Food, Agriculture and Fisheries since 2010 (DEA, 2012a). The future of the support scheme is unclear. Resources have been set aside for afforestation projects, which will increase the potential for Danish wood chips and pellets for energy use.

5.3 Incentives

Energy fees exist for coal, oil, petrol and natural gas. Fuel used for electricity production is exempted from these fees. Instead, Denmark has a tax on all electricity including that from renewable sources (DEA, 2012a). A support scheme for renewable energy was introduced to support its development. The law on support of renewable energy (Law nr 1392 from 27/12/2008) specifies the extra amount of money that a producer of electricity from biomass will get added on top of the market price for electricity.

A fee on SO₂ emissions covers both fossil fuels and biomass that are used in heat and power stations with a capacity above 1000 kW (DEA, 2012a). A similar fee exists for nitrogen mono-dioxides (NO_x) emissions.

A fee on carbon dioxide emissions from fossil fuels is added on companies in sectors not covered by the EU ETS. A CO₂ emissions fee is also added on top of the electricity price, even though electricity producers are part of the EU ETS. An exemption from the latter fee will be made for companies starting from 2014 to spur economic growth (DEA, 2012a). Biofuels for transport are also exempted from the CO₂ emissions fee, since they are seen as being carbon neutral. A mineral oil fee is however in place for biofuels used in the transport sector, at a level equal to the one on petrol (DEA, 2012a).

The EU ETS is a cap and trade system with the ambition to reduce GHG emissions in a cost efficient way (European Union (EU), 2014). The system was introduced in 2005 and covers the energy production sector and energy-intensive industry sectors. Emission allowances were distributed according to national allocation plans, with a cap on the total amount of allowances. Companies either receive allowances or buy them. Each allowance equals one tonne of CO₂ (or the equivalent GWP for other greenhouse gases). The holder of an allowance can choose to emit the CO₂ or trade the allowance on a market with a company than wants to emit more. The total number of allowances is set to decrease with a certain percentage every year. Biomass that adheres to the definition made by the EU is seen to have zero CO₂ emissions, thus emission allowances are not needed for energy produced from biomass (European Commission (EC), 2012).

A fee on heat from waste incineration is levied in Denmark. Biomass waste is exempted from this fee. Proposals currently under consideration by the Danish Parliament could reduce the relative economic advantage that energy from biomass has compared with energy from fossil fuels.

5.4 Sustainability

The use of biomass for energy on an ever growing global scale has garnered concerns from scientists, environmental groups, and governments over the years. The principle concerns center around the potential negative effects that the increased production of biomass would have on land use, land competition, and land management. Sustainability issues include GHG emissions caused by the conversion of carbon-rich savannahs to bioenergy plantations, emissions associated with indirect land use change, the environmental impact of large scale expansion of bioenergy production on local ecosystems, the effects on food prices caused by direct and indirect land use change, and effects on local livelihoods of bioenergy deployment. Within the EU, concerns have focused on competition for food production and the net GHG balance when direct and indirect land use changes are considered.

Several environmental issues arise from the production of energy from biomass. The main ones are CO₂-balance, N-leaching, pesticide use, changes in C-stock of soils, biodiversity, and reduction of landscape values and reduced groundwater recharge (Abbasi & Abbasi, 2010; Jørgensen et al., 2013; Dalgaard et al., 2010). An important factor when assessing the environmental impacts is whether the resource is a residue, a waste product, or a primary product. Waste and agricultural residues are the main forms of biomass produced in Denmark for energy production. The use of agricultural residues can have an impact on the carbon stock of the soil, since removing straw reduces the amount of nutrients returned to the soil (Gregg and Izzaraulde, 2010). In forests, removing waste and residuals can reduce biodiversity because many organisms decompose branches and pieces of wood left on the forest floor, as well as other fauna that have their habitat in dead organic matter and natural forest residues. Debate and negotiations are still ongoing in the EU concerning environmental sustainability standards for bioenergy (see below).

Regarding the effects of bioenergy deployment on food supply, the EU limits the amount of bioenergy that can be derived from food crops. The Renewable Energy Directive (2009/28/EC), part of the EU's climate change mitigation strategy, sets a goal to produce 20% of the EU's energy consumption from renewable energy sources. The directive lays out requirements for guarantees of origin for renewable fuels used to produce electricity, heating and cooling, as well as outlining sustainability requirements for the production of liquid biofuels. In October of 2012, in an attempt to limit global land use change for biofuel conversion, the European Commission stipulated that no more than 5% of the total renewable energy can come from food crops.

In the current CO₂ accounting practice under the Kyoto Protocol to the United Nations Framework Convention on Climate Change, biomass fuels are considered as CO₂ neutral, although the combustion leads to physically more CO₂ emissions than coal at the combustion site. The global balance depends on the CO₂ uptake where the plants are grown. This value may vary significantly and there is currently no agreed method for accounting of CO₂ uptake. Within the EU, sustainability criterion for biomass for bioenergy

is still an on-going debate. In 2009, the Commissions held a public forum to develop sustainability criteria for *solid* biofuels. Even though 90% of the participants supported the idea of a common framework that codified specific, mandatory sustainability criteria across the EU, there was nevertheless opposition from key bioenergy producers in the major biomass producing countries. Therefore, the Renewable Energy Directive did not outline specific sustainability requirements for the production of biomass for bioenergy, yet the Commission recommended that sustainability criteria be established on the national scale. Furthermore, an Annex is included that gives methods for calculation of the GHG emissions for different types of liquid biofuels. Work on sustainability criteria for solid biomass continues and mandatory guidelines may soon be adopted into the Renewable Energy Directive. Currently, the sustainability recommendations on liquid biofuels given in Article 17 of the Directive include (European Commission, 2010):

- No biomass should be sourced from converted native forestland, areas with high biodiversity, and areas with large amounts of carbon stored within the ecosystem.
- A common GHG calculation should be employed to ensure that CO₂ emissions are reduced by at least the minimum requirement. The recommended minimum requirement is currently 35% reduction in CO₂ emissions, but this rises to a 60% reduction for new installations made after 2018.
- National energy strategies that concern biomass should support those technologies and processes which have high energy efficiency.
- Careful monitoring of the origin of imported biomass is recommended.

In September of 2011, the European Environment Agency Scientific Committee strongly recommended that biomass produced from existent forests should not be considered as carbon neutral. Instead, the committee recommended that European policies should favor biomass grown on marginal land or be sourced from residues. The Commission agreed to count waste biomass as double towards the Renewable Energy Target. This position was also adopted by Denmark (Concito, 2011) and environmental sustainability considerations are a key component to the Danish strategy of incorporating a greater share of biofuels into the national energy portfolio. Therefore, the details of how the biomass is produced and supplied are important to consider. Biomass can be produced in a sustainable way such that it benefits the environment, but it can also be produced in a non-ecological way. For this reason, Denmark has funded research on life cycle assessments (LCAs) to determine the extent of the benefit for incorporating a larger share of biomass into the energy system. Analysis conducted by the Danish Energy Agency (DEA) determined that biomass does have a net carbon benefit over fossil fuels, as long as it is not sourced from plantations that have been converted from natural forest land (DEA, 2012a). Further research is being conducted to determine the effect on indirect land use change resulting from increased biomass demand. In addition, biomass was also determined to be a net benefit for carbon emissions if a long time scale (greater than 100 years) is considered, even if forest land is converted (DEA, 2012a). Nevertheless, Denmark is concerned that imported biomass may not always come from sustainable sources, and that as the demand for biomass continues to increase worldwide, many forests will be managed primarily for energy production purposes.

In addition, the DEA (2012a) developed a set of conditions for utilizing biomass for energy and transportation that strive to ensure sustainability and efficiency.

Environmental sustainability criteria include:

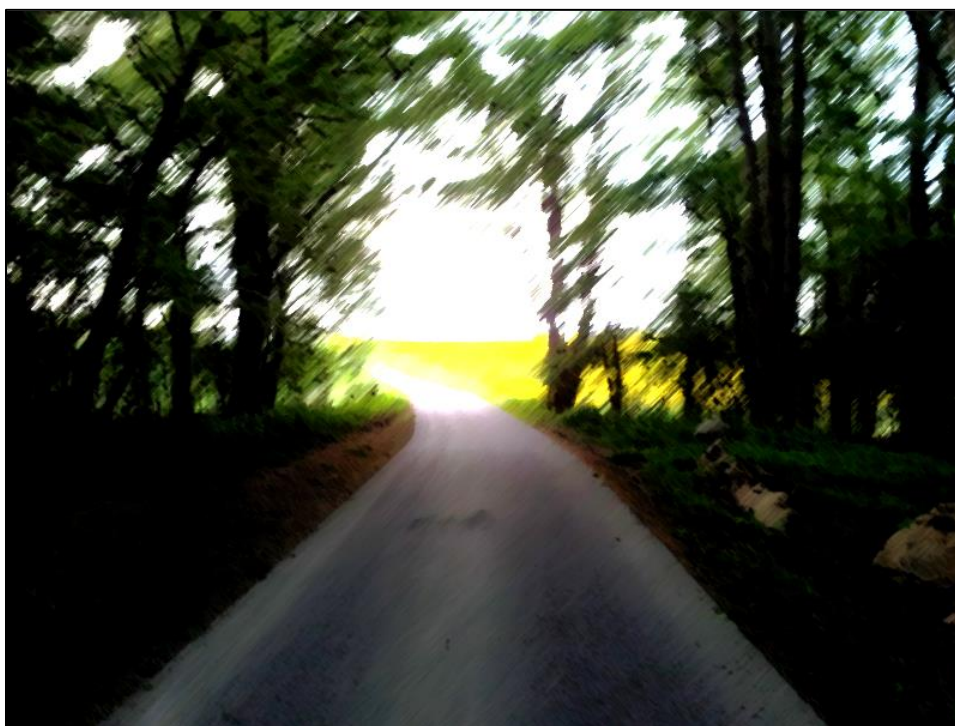
- In order to increase the likelihood of stabilizing global greenhouse gas emissions by 2050, and obtaining no more than a two-degree warming by 2100, the use of biomass should be done in such a way that it represents real reductions in GHG emissions.
- Biodiversity should be maintained or improved wherever biomass for bioenergy is produced.
- Soil quality should be maintained or improved (including nutrient content, soil structure, and carbon content) wherever biomass is produced.
- Water quality should be maintained or improved (including impacts through the release of pesticides and excess nitrogen) wherever biomass is produced.
- Air quality should be maintained or improved (including impacts through the release of SO₂, NO_x, and particulates) wherever biomass is produced.
- It is crucial that the use of biomass for energy and transport does not negatively impact global food security.

The efficient use of biomass for energy and transport is characterized by:

- Biomass materials and technologies should be used in the most cost efficient manner possible to reduce the cost of the Danish energy strategy.
- Biomass should aid in the national goals for energy security, including:
 - Security of electricity supply—that there is a low probability for electricity shortages when demand peaks, and electrical power is always available on demand.
 - Security of fuel supply—this is assessed primarily from the degree of geographic concentration of an internationally traded energy resource in relation to the scope of application of this in a given energy and transport system.
- High energy and resource efficiency—the total energy balance (energy input versus output) should be greater than one, and as large as possible. This also encompasses a high degree of recovery of all fractions of a given type biomass for a number of purposes.

Currently, these guidelines focus on environmental sustainability and efficiency aspects, and do not consider social aspects. However, the Danish government has published a guide on public procurement of sustainable timber in which the sustainability criteria also includes other elements, including the maintenance of forest resources and their production and a number of aspects of social sustainability. The guidelines are now being revised and updated and will come to underlie the official Danish policy to ensure sustainable timber in imported wood-based products and services.

6 Future Perspectives



6.1 Future Resource Potential

In recent years, several analyses of Danish biomass potentials have been carried out. The overall conclusions point to the possibility of deriving more biomass suitable for energy production without harming the environment and reducing food production. The analyses also conclude that the largest potential lies within the agricultural sector. The assessments also points to more limited sources like grass from meadows and roadsides.

Another potential biomass resource is seaweed cultivated in coastal areas. This technology is well described and used globally to produce seaweed for the food and medical industries. Since Denmark has a very long coastline and an optimal climate for seaweed cultivation this could be a future biomass resource. Growing seaweed in coastal areas also has the benefit of removing excess nutrients leached from agriculture.

Future plans also include increasing the use of biomass to produce fuels for the transportation sector. Denmark does not currently produce transport biofuels at a commercial scale, but given the substantial RD&D efforts in Denmark (see section 5) and elsewhere in recent years, the production of advanced biofuels will likely increase substantially in the years to come, supplementing or replacing the productions of 1G fuels.

6.2 The Role of Biomass in a Future Fossil-Free Energy System

Fossil fuel-independent energy scenario analyses for Denmark recently published by the DEA (2014b and 2014c) present scenarios in which the share of biomass in the future Danish energy mix is significantly increased. The scenarios were constructed for 2020, 2035, and 2050 and are all technically consistent (with future energy demand modeled at a one hour time-scale) and rely on known technologies while assuming their further

development in terms of price, efficiency, and performance capability (DEA, 2014c). The scenarios represent different views on, or projections of, the future role of biomass in the Danish energy system (Table 3). The scenarios should not be understood as detailed forecasts or final answers about the actual or preferred design of the future energy system. Neither do the scenarios include any specific recommendations on which instruments are needed to realize the scenarios. There are five scenarios for the future Danish energy system, but here we focus here on the Wind scenario and the two Biomass scenarios (*Biomass* and *Bio+*) for 2050.

Resource	Scenario				
	<i>Wind</i>	<i>Biomass</i>	<i>Bio+</i>	<i>Hydrogen</i>	<i>Fossil</i>
Biomass (domestic)	171	308	393	108	31
Net imported biofuel	0	50	231	0	0
Biogas	42	42	42	42	17
Waste	42	43	43	41	44
Wind power	246	113	76	295	113
Other renewables	86	86	47	93	38
Fossil fuels	0	0	0	0	391
<i>Share of renewables</i>	<i>97%</i>	<i>97%</i>	<i>97%</i>	<i>97%</i>	<i>37%</i>
<i>Net self sufficiency</i>	<i>104%</i>	<i>79%</i>	<i>58%</i>	<i>116%</i>	<i>NA</i>

Table 3. Energy scenarios for Denmark to 2050. Key energy data for year 2050 in PJ. 'Other renewables' are solar PV, solar heating, and geothermal. Net self-sufficiency refers to the share of net imports in total energy consumption. The share of renewables is less than 100% in the non-fossil scenarios due to non-renewable content in waste. Data for imported biofuels and biomass in the Biomass, Bio+ and Hydrogen scenarios include conversion losses and transport abroad. Source DEA, 2014c.

The *Wind Scenario* involves limited use of biomass (213 PJ) and was designed to represent a situation with zero net imports of biomass in view of the possible risks associated with a high reliance on imported biomass (Table 3). The numbers reported here relating to energy from biomass excludes energy from waste (even if part of this waste is of organic origin). This scenario requires large-scale deployment of off-shore wind power and a massive electrification of the energy system – including in transport, industry and district heating. Upgrading of biomass and biogas with hydrogen also contributes to the low use of biomass resources.

In the *Biomass Scenario*, biomass in various forms contributes 400 PJ in 2050, of which 50 PJ (12.5%) is imported. This scenario also involves large scale electrification of the energy system; although lower than in the *Wind Scenario*, as the deployed biomass is far from sufficient to replace the use of coal, oil and gas. Transport relies both on electricity and biofuels. The *Bio+ Scenario* represents a conventional fuel combustion system much like today's, where biomass fully replaces fossil fuels for transport, power and heating, with a limited role of wind. No attempt is made to limit biomass use, which increases substantially compared to the present, requiring large imports of both solid and liquid biofuels as well as an increase in domestic production.

6.3 Future Prospects for Bioenergy Deployment in Transport

The transport sector consumes very large amounts of biofuels in all the scenarios discussed above, even with a high level of electrification, placing the sector at the center

of sustainability discussions about the future energy system. Furthermore, transport accounts for about half of the costs of a fossil fuel independent energy system in 2050. These observations suggest that energy efficiency gains in the transport sector have large potential benefits. No assessment exists of the competitive situation for Danish biofuel production compared to imported biofuels. Furthermore, while there are plans to build commercial-scale production plants for biofuels in Denmark, as of yet, none have been built, but several plants are being constructed elsewhere in the world. Domestic production of biofuels for transportation would enable the realization of industrial symbiosis effects from the co-location of waste treatment and different energy-producing facilities, such as district heating, CHP, biogas and bioethanol. A case in point is the Maabjerg Energy Concept, discussed in Section 5.

The largest biofuel demonstration plant in Denmark is operated by Inbicon Biomass Refineries (www.inbicon.com), which produces 2G bioethanol from lignocellulosic biomass using enzymatic hydrolysis and C5 sugar fermentation or C5+C6 mixed sugar fermentation. The ethanol is blended with gasoline at 5% (E-5) at retail petrol stations across Denmark. Valuable main co-products are lignin pellets for combustion in power plants and C5 molasses suitable for livestock feed or as a biogas booster. The Inbicon technology uses enzymes supplied by the Danish company Novozymes, among other others, and has been licensed to plants globally. In early 2014, Inbicon entered into a partnership agreement with Neste Oil to develop cellulosic sugars for further refining into microbial oils to be used for renewable diesel and jet fuels.

Other Danish companies undertaking RD&D activities relating to 2G bioethanol include Biogasol (www.biogasol.com) and IBUS Innovation (www.ibusinnovation.dk). Danish universities are strongly engaged in research on the technical, socio-economic and environmental aspects of biofuel production and bioenergy more broadly.

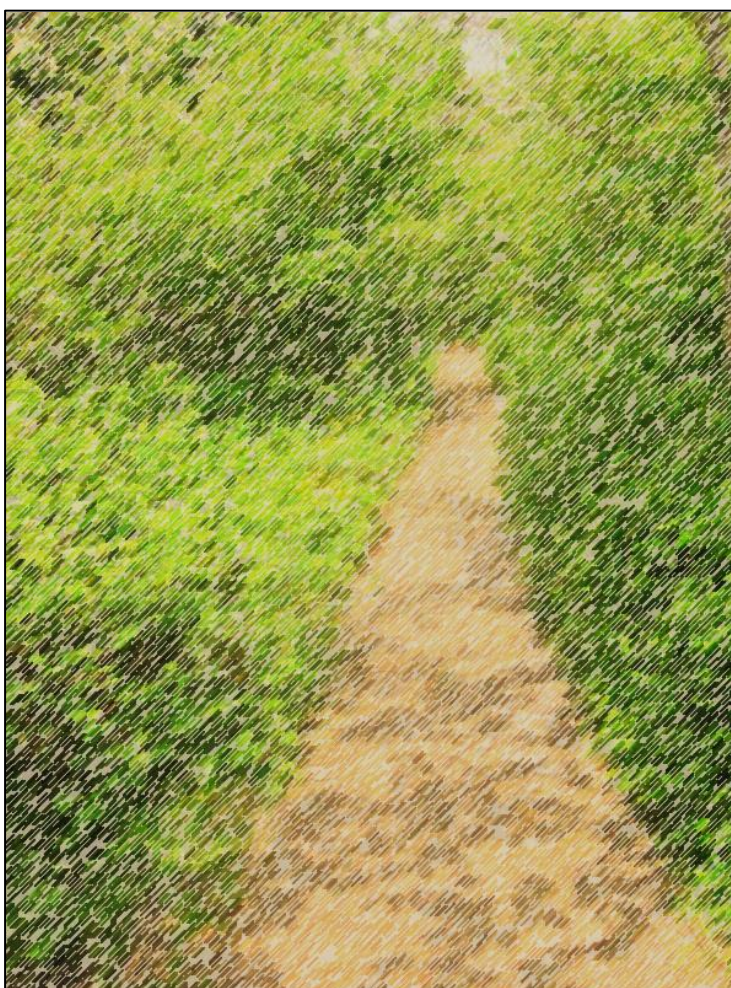
6.4 Risks and Uncertainties Associated with Increased Bioenergy Consumption

There are important environmental, economic and social risks associated with an increased reliance on biomass for energy. In the short-term, up to around 2020, DEA (2014b) estimates that the increase in biomass use can be covered by domestic organic waste and residues and by imported wood pellets and wood chips from sustainably managed forests. Hence, relatively few environmental sustainability (including GHG emission) issues are foreseen in this period. In the longer term, however, the regional and global competition for biomass is expected to intensify as other countries also begin to implement stringent climate and energy policies, in turn increasing the risk that importers of wood products are "pushed" towards unsustainably produced biomass (DEA, 2014b). The uncertainty surrounding the future access to affordable and sustainably produced biomass is reflected in the rich literature that exists on this subject – including analyses of alternative scenarios for the future role of biomass in energy systems (Creutzig et al, in press; IPCC, 2011). It also suggests the need to develop and implement strong international sustainability standards for both liquid and solid biofuels (see Section 7.4). In this regard, local-specific factors as well as large-scale market and regulatory dynamics affect the sustainability of biofuel production. Assessments of the sustainable bioenergy potential are thus inherently uncertain and context dependent (Creutzig et al., 2013;

Creutzig et al., in press). Finally, a high level of efficiency in the use of biomass, and in the energy system as a whole, is a key factor in mitigating the risks associated with the use of biomass for energy on a large scale.

7 Conclusion

As Denmark seeks to achieve its goal of a fossil free energy system, energy from biomass will play an ever increasing role. Denmark stands at the forefront in terms of research and technology in utilizing biomass efficiently and for converting it into a more environmentally friendly transport fuel. Looking to the future, the challenges for Denmark will be to ensure it can continue to find sources of sustainably produced biomass at competitive prices.



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As Denmark seeks to achieve its goal of a fossil free energy system, energy from biomass will play an ever increasing role. Denmark stands at the forefront in terms of research and technology in utilizing biomass efficiently and for converting it into a more environmentally friendly transport fuel. Looking to the future, the challenges for Denmark will be to ensure it can continue to find sources of sustainably produced biomass at competitive prices.

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